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POSTURAL RESPONSES TO BALANCE PERTURBATION IN YOUNG AND OLDER ADULTS

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Declaration:

With the exception of any statements to the contrary, all the data presented in this report are the result of my own efforts. In addition, no parts of this report have been copied from other sources. I understand that any evidence of plagiarism and/or the use of unacknowledged third party data will be dealt with as a veryserious matter.

Signed ....

Date ....

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Abstract

Postural control is used to maintain balance whilst standing in an upright position. With ageing, postural control following a perturbation, may decrease. This could lead to more falls, potentially causing injuries and hospital visits. The three main sensory systems contributing to balance are the visual system, vestibular system, and the somatosensory system. The aim of this study was to determine the changes in reaction to postural perturbation between Young, Middle Aged and Old adults (Aged 19-34 years, 35-59 years and 60-76 years respectively). Participants provided written, informed consent and their weight (kg), height (cm) and age (years) was recorded. Using the Natus neurocom balance master, each participant participated in the sensory organisation test, the motor control test and the unilateral stance test, and their reaction to the perturbation was recorded. The main findings of the study indicated that young adults do not need visual input to maintain balance when the visual input is accurate, however when the visual input is disturbed,

'young', 'middle aged' and 'old adults' experience reduced balance stability. It was also observed that 'Young' adults are the only age group in the study able to rely on the somatosensory system to maintain balance, whereas none of the age groups could use to vestibular system alone to maintain balance.

1. Introduction

Maintaining upright posture is important for controlling balance to avoid falling, particularly in response to unexpected disturbances during usual human locomotion such as standing, walking and running. Postural control can be defined as the act of maintaining, achieving or restoring a state of balance during any posture or activity (Low et al., 2017). Postural control strategies may be either predictive or reactive and may involve either a fixed support or a change-in-support response (Pollock et al, 2000). Balance can be defined as the state of an object when the resultant force acting upon it is zero, with human balance being defined as ‘a multidimensional concept, referring to the ability of a person not to fall’ (Winter et al, 1995). Postural control and balance are often compromised in older age and are associated with their increased risk of falling. A fall is defined as an incident, which causes a person to, accidentally, rest on the ground or lower level, and is not the result of a major intrinsic event, such as a stroke, or overwhelming hazard (Currie, 2007). Falls can become frequent and result in injuries including head injuries and hip fractures. People aged 65 years and older have the highest risk of falling of any adults; around a third of people aged 65 and over, and around 50% of people aged 80 and over, fall at least once a year. Falling is a cause of distress, pain, injury, loss of confidence, loss of independence and mortality (Public Health England, 2018).

1.1 Falls

The Public Health Outcomes Framework (PHOF) reported that in 2013 to 2014, around 255,000 emergency hospital admissions in the UK were due to falls among patients aged 65 and over, with around 173,000 (68%) of these patients aged 80 and over. In 2013, falls were the ninth highest cause of disability-adjusted life years and the leading cause of injury (Public Health England, 2018), with unaddressed fall hazards in the home costing the NHS in England an estimated £435 million. The total cost of fractures caused by falls in the UK has been estimated at £4.4 billion, including £1.1 billion for social care following a fall, with hip fractures accounting for £2 billion of this total. Following a hip fracture, short and long-term outlooks for patients are poor with an increased one-year mortality of 18-33%, as well as having negative effects on daily activities such as shopping and walking. It was also found that around 20% of hip fracture patients entered long-term care within a year of having the fracture (Public Health England, 2018).

Possible causes of the increased prevalence of falls amongst older adults compared to young adults include diminished sensory and cognitive performance or neuromuscular control. Sensory contributions include vestibular, visual and proprioceptive functions interpreted in the brain to effect perceptions and generate the motor command for the corrective responses.

1.2 Sensory Systems

Balance control can refer to sway when standing still or control during a perturbation. During standing, vision, proprioception and vestibular inputs provide information about the body's positioning in the environment (Perterka, 2002). The input from each of these sensory systems and how they relate to the internal representation of the body's orientation and equilibrium depends on how the central nervous system assigns weight to each sensory modality (Stevenson et al, 2007). Several studies have shown that the sensory receptors that monitor body orientation are less sensitive in older than younger adults (Goble et al, 2009; Gu et al, 1996). The reduced sensitivity has been linked to an increased incidence of falling and overreliance on visual feedback, which can disrupt postural control when visual inputs are diminished or unreliable (Horak,2006; Simoneau et al.,1999; Wade et al., 1995; Jeka et al, 2006). As well as reductions in sensory reliability, delays in the transmission of feedback from the lower limb can exceed several tens of milliseconds (Purves et al, 2001). These feedback delays can cause problems as the neural circuitry used for postural control relies on input to correct balance errors (Lockhart et al, 2007). Despite evidence that sensory delays increase during aging (Blaszczyk et al, 1993) it is unclear how these additional feedback delays effect standing balance.

The ability to maintain balance deteriorates with increasing age, as sensory and motor controls required for postural stability decline with ageing. Preemptive and compensatory postural adjustments are both known to be effected in the elderly (Kanekar et al, 2014). The relation between balance control and independent mobility is important in the elderly where poor postural control is associated with significant mobility losses, physical inactivity and an increase in the fear of falling (Frank and Patla., 2003; Merom et al., 2012; Skelton and Beyer 2003).

Understanding which sensory system takes highest priority for balance control in young and if the sensory input-weighting changes through middle aged and old age will help to define the most effective countermeasures to prevent falls in old age. Postural Control is a complex interaction between the sensory and motor systems, which involves perceiving
environmental stimuli, responding to alterations in the body's orientation in
the environment and maintaining the body's centre of gravity within the base
of support (Shaffer and Harrison, 2007).

1.2.1 Visual System

The visual pathway consists of cells and synapses that carry visual information from the environment to the brain for processing. It includes the retina, optic nerve, optic chiasm, optic tract, lateral geniculate nucleus (LGN), optic radiations and striate cortex. The first cell in the pathway is the photoreceptor, which is a special sensory cell. It converts light energy into a neuronal signal that is passed to the bipolar cell and the amacrine cell and then to the ganglion cell, which are all located in the retina. The axons of the ganglion cells exit the retina via the optic nerve, with the fibres from each eye crossing in the optic chiasm and terminating in the opposite side of the brain. The optic tract carries these fibres from the chiasm to the LGN, where the next synapse occurs. The fibres leave the LGN as the optic radiations that terminate in the visual cortex of the occipital lobe. From various points in this pathway, information about the visual environment is transferred to visual association areas (Remington, 2012).

Afferent and Efferent motion perception is involved in the development of the visual system. Afferent motion perception involves awareness of objects in the environment whereas efferent motion is the control of the eyes, body or head (Kapoula & Thuan, 2006).

1.2.2 Vestibular System

The vestibular system is the apparatus of the inner ear involved in balance. It is made up of two structures of the bony labyrinth, the vestibule and the semi-circular canals, and the structures of the membranous labyrinth contained within them. The

Vestibular system is thought to be a leading contributor to maintaining balance and having spatial orientation with the purpose of coordinating movement. The vestibular input works alongside the visual and somatosensory system to maintain postural control (Merla and Spaulding, 1997). The importance of an accurate sensory perception of the environment is most apparent when there is not an input from the vestibular system or the input is not appropriate. Without accurate vestibular input there are also significant debilitating balance deficits and an range of symptoms including dizziness, instability, vertigo, nausea, paleness, diaphoresis, general malaise, and even emesis. Depending on the severity, these symptoms can often lead to physical, mental, and even social isolation (Hear, 2015).

1.2.3 Somatosensory System

The somatosensory system is involved in the conscious perception of touch, pressure, pain, temperature, position, movement, and vibration. The somatosensory system comprises of three neurons; primary, secondary and tertiary. It relays sensations detected in the periphery and conveys them via pathways through the spinal cord, brainstem, and thalamic relay nuclei to the sensory cortex in the parietal lobe (Gleveckas-Martens et al,. 2013).

1.3 Ageing and Balance

Ageing effects all levels of neural processing, including intracortical inhibition and cortical excitability, which suggests a decline in somatosensory processing with ageing (Lens et al, 2012). This could be detrimental to balance as during quiet standing, the somatosensory system is most important for keeping upright, stable body position. When the reliable proprioceptive information from feet and ankles is altered, which can be caused by standing on uneven and moving surfaces, the somatosensory system becomes less reliable at assisting with balance causing individuals to more heavily rely on visual, vestibular and motor systems to maintain stability (Colledge et al. 1994, Lord and Menz.
2000, Choy et al. 2003). Although it is known that the somatosensory system, visual system and vestibular system are all vital to maintain balance, it remains unclear how the sensory inputs change with ageing, if there is a rebalancing of sensory system control balance, or what happens during situations where some sensory inputs are disturbed. To determine this, we used the Neurocom balance master, using the Sensory Organisation Test, The Motor Control Test and the Unilateral Stance Test.

This study could be vital in the development of new strategies to prevent the high incidence of falls among the elderly, as more targeted strategies could be focused on improving either the somatosensory, visual or vestibular system.

1.4 Measurements

1.4.1 Sensory Organisation Test

The Sensory Organisation Test (SOT) objectively identifies any abnormalities in the three sensory systems, which contribute to postural control: the somatosensory, visual and vestibular system. During the SOT, inconsistent information delivered to the eyes, feet and joints is controlled through sway of the support surface and visual surround. Sensory conflict situations, which stress the adaptive responses of the central nervous system, are created by controlling the use of sensory information from the three different systems through sway referencing and/or eyes open/closed conditions.

Accurate organisation of sensory information is critical to maintain balance in everyday life. When individuals have an inability to organise somatosensory information appropriately, they may be unable to maintain stability in environments where visual cues are diminished (e.g. darkness), the surfaces are unstable (e.g. sand and gravel), or where conflicting visual stimuli are present (e.g. in a busy shopping centre, in cars and on boats). An Inability to appropriately organise sensory information can lead to, or be intensified by, impairments in Centre of Gravity (COG) alignment and/or selection of movement strategies.

1.4.2 Motor Control Test

The Motor Control test is used to quantify an individual's ability to quickly recover following an unexpected external disturbance. This is test involves sequences of small, medium and large platform translations in forwards and backwards directions to elicit automatic postural responses. A delay in automatic motor response suggests limited functional outcome.

1.4.3 Unilateral Stance Test

The Unilateral stance test quantifies the ability to maintain postural stability whilst standing on one leg, with eyes open and with eyes closed. It enhances the observational testing of single leg stance performance by providing an objective measure of patient sway velocity for four different task conditions. The Unilateral stance test is highly sensitive, but not specific as there are a large number of independent factors which can impact performance.

1.5 Hypothesis Aim and Objectives

It was hypothesised that ‘Old’ would have reduced balance, reduced visual strategy, use more hip strategy, have a slower reaction time, and have more difficulty when trying to maintain balance on one leg.

AIM: To determine the changes in reaction to postural perturbation between Young, Middle Aged and Old adults.

Objectives

1. Conduct a “sensory organisation test” to assess the vestibular, visual and proprioceptive contributions to posture during standing and after perturbation in adults ranging in age from 18-80 years using the Neurocom Balance Master.

2. Conduct a “Motor Control Test” to assess the ability of the automatic motor system to quickly recover following an unexpected external disturbance in adults ranging in age from 18 to 80 years using the Neurocom Balance Master.

3. Conduct a ‘Unilateral Stance Test’ to assess the ability to maintain postural stability whilst standing on one leg, with eyes open and eyes closed in adults ranging in age from 18- 80 years using the Neurocom Balance Master.

2. Methods

The study was a cross sectional study including laboratory assessment.

2.1 Participants, Consent and Ethical Approval

The study was approved by the University Research Ethics Committee of the Manchester Metropolitan University and conducted in accordance with the *Declaration of Helsinki (2013).* Sixty-two untrained men and eighteen untrained women aged nineteen to seventy-six years participated in the study and provided informed written consent. All participants were healthy with no cardiovascular or neuromuscular conditions, and no diagnosed balance disorders, and able to give informed consent. Participants with visual impairments were eligible for the study and were allowed to wear their usual glasses but no further assessment was made.

Participants recruited from the study were both 'Manchester Metropolitan University' staff and the general public, who were both recruited using word of mouth.

The participants had to come into the lab on just one occasion for around two hours. After determination of height (cm) and body mass (kg) the participants were subjected to three balance tests on the 'Natus NeuroCom SMART Balance Master' (Natus medical incorporated, Pleasanton, USA): a sensory organisation test (SOT), motor control test (MCT) and a unilateral stance (US) test. For all tests, participants were barefoot and wore a harness attached to the Balance Master to prevent any injuries caused by falling when losing balance during any of the tests.

Figure 1. *Photo showing Natus Neurocom SMART Balance Master*

2.2 Sensory Organisation Test

2.2.1 SOT Protocol

To perform the SOT tests, participants were subjected to 6 different sensory conditions (Fig. 2). Each condition comprised of up to three trials lasting 20 seconds each. In condition 1, the participants stood quietly with their eyes open, while in condition 2 participants stood with eyes closed. These two conditions establish whether sway increases when visual cues are removed and how effectively the participants uses somatosensory input. In condition 3, the participant stands with their eyes open whilst the visual surround is sway-referenced, making visual cues inaccurate. In Condition 4, the support surface becomes sway-referenced, making somatosensory cues inaccurate. Condition 5 is performed with eyes closed and a sway referenced support surface, to determine how the participant uses vestibular cues when visual cues are removed and somatosensory cues are inaccurate. In condition 6, both the support surface and the visual surround are sway referenced, to identify if the participant relies on visual cues even when they are inaccurate.

Participant scores are evaluated after each trial. Trials are interrupted if the participant appears to require any assistance. For instance, if a participant falls or takes a step, the space bar was pressed to mark this interruption.

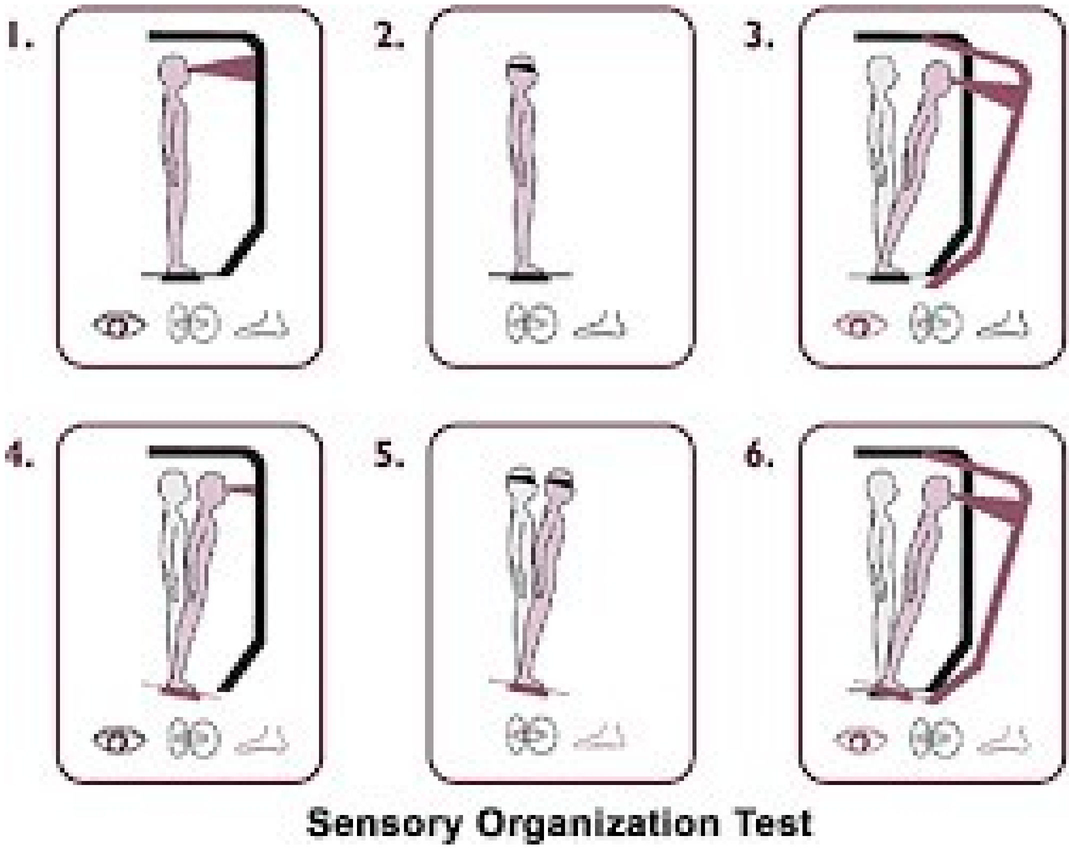


Figure 2. *Diagram from 'Neurocom International. Inc' showing the six conditions of the sensory organisation test.*

Note: *Condition 1: Open eyes, fixed support surface, fixed visual surround; Condition 2: Closed eyes, fixed support surface; Condition 3: Open eyes, fixed support surface, sway-referenced visual surround; Condition 4: Open eyes, sway-referenced support surface, fixed visual surround; Condition 5: Closed eyes, sway-referenced support surface; Condition 6: Open eyes, sway-referenced support surface, sway-referenced visual surround.*

2.2.2 SOT Comprehensive Report

The Balance master produces a comprehensive report with equilibrium score, sensory analysis, strategy analysis and centre of gravity (COG) Alignment. The Equilibrium Score, an overall indicator of balance quantifies the COG sway or postural stability during the trials of each of the six sensory conditions. The overall pattern of scores on the six conditions is used to determine if there has been effective use of individual sensory inputs. It is computed according to equation 1.

$$\frac{12.5^\circ - (\theta \max - \theta \min)}{12.5^\circ} * 100 \qquad \text{Equation 1}$$

Equation 1 *12.5^0 represents the maximum normal postural sway in the anterior posterior direction and θ represents the calculated maximum anterior-posterior COG displacement. A score of 100 signifies perfect stability whereas a score of 0 indicates a loss of balance.*

For the sensory analysis, ratios are used with the individual equilibrium scores to identify impairments of the individual sensory systems (Table 2).

Ratio	Comparison	Functional Application
Somatosensory (SOM)	Condition 1 / Condition 2	Ability to use input from somatosensory system to maintain balance
Visual (VIS)	Condition 4 / Condition 1	Ability to use input from the visual system to maintain balance
Vestibular (VEST)	Condition 5 / Condition 1	Ability to use input from vestibular system to maintain balance
Preference (PREF)	Condition 3 + 6 / Condition 2 + 5	The degree to which the participant relies on visual information to maintain balance, even when the information is incorrect

Table 1. *Showing how the sensory analysis is calculated and the purpose of it.*

2.2.3 Strategy Analysis

The Strategy Analysis quantifies the relative amount of movement about the ankles, known as 'Ankle Strategy', and about the hips, known as 'Hip Strategy', used by the subject to maintain balance during each trial. Normally, individuals primarily use an ankle strategy when the surface is stable, and begin to use a 'hip strategy' as they become less stable. A score near 100 indicates a full ankle strategy, whereas a score near 0 indicated a full hip strategy.

2.2.4 Centre of Gravity (COG) Alignment

The COG Alignment reflected the subject's COG position relative to the centre of the base of support at the beginning of each SOT trial. Individuals with no balance impairment would be able to maintain their COG near the centre of the support base.

2.3 Motor Control Test (MCT)

The Second test was the motor control test, which assesses the ability of the automatic motor system to quickly recover following an unexpected external disturbance. Each participant completed six conditions for the MCT, consisting of three forwards and three backwards translations, which were graded in magnitude (small, medium, and large (figure 3). The size of the translations are scaled to the participant's height. At the start of each condition, the feet where correctly positioned on the support surface. The trials were performed in a standardised order: backwards translations first, then forwards translations. If the participants lost their balance, the trial was interrupted and the fall was marked.

A full MCT took around 10 min to complete for each participant. The software computed the following parameters: weight symmetry, latency and amplitude scaling (Table rather than Table 3).

	SMALL TRANSLATION	MEDIUM TRANSLATION	LARGE TRANSLATION
BACKWARDS TRANSLATION	***CONDITION 1***	***CONDITION 2***	***CONDITION 3***
FORWARDS TRANSLATION	***CONDITON 4***	***CONDITION 5***	***CONDITION 6***

Table 2: Table showing the characteristics of each condition (1-6) for the motor control test.

NOTE: The small translations represent a threshold stimulus whilst the large translations require the participant to produce a maximal response. The medium translations are in between the two ends of the spectrum. Each condition is performed three times, with a random, computer generated, delay of 1.5 to 2.5 s in between each condition. The horizontal displacement of the support surface during each translation is scaled according to the height of the participant. Three parameters are calculated: Weight Symmetry, which provides information relative to distribution of weight on each leg; Amplitude Scaling, which quantifies the strength (efficacy) of responses for both legs and for the three translation sizes; and Latency, which quantifies the time between the stimulus (force plate translation) and the patient's active force responses in each leg.

2.4 Unilateral Stance Test

The Third test was the Unilateral Stance Test (US). The US quantifies the ability to maintain postural stability whilst standing on one leg, with eyes open and with eyes closed. The US test enhances the observational testing of single leg stance performance by providing an objective measure of patient sway velocity for four different task conditions. The US test is highly sensitive, but not specific as there are a large number of independent factors which can impact performance, including: lower limb strength; weight bearing control; sensory balance control; movement strategies and prior practice with the task.

2.4.1 US Stance Protocol

Each Participant conducted up to three trials for the four conditions of the US Test, standing on the right then left leg, with eyes open then closed (see Table 4). Each trial lasted for ten seconds.

	EYES OPEN	EYES CLOSED
LEFT LEG	*CONDITION 1*	*CONDITION 2*
RIGHT LEG	*CONDITION 3*	*CONDITION 4*

Table 3. *Table showing the characteristics for conditions 1-4 of the unilateral stance test: left eyes open, left leg eyes closed, right leg eyes open, right leg eyes closed respectively.*

2.4.2 Unilateral Stance Comprehensive Report

Following the US test, the COG Traces for each trial and Mean COG Sway velocity were calculated.

2.4.3 Functional Implications

When standing upright, individuals have significantly more sway whilst standing on one foot with closed eyes compared with eyes open. Participants may become unstable due to difficulty using visual or somatosensory information for balance control, and/or may have musculoskeletal problems that make it difficult to correct lost balance. Functional consequences are significant for performance or activates that require single leg balance (such as getting dressed, stairs/steps, or navigating narrow support surfaces such as ladders).

2.5 Statistical Analysis

The data was analysed using SPSS statistical software (IBM, USA, v24). All data was tested for normality of distribution using Kolmogorov-Smirnov test.

A repeated-measures ANOVA was used with as within factor 'condition' and as between factors 'sex' and 'group'. If a significant group effect was found a Bonferroni corrected post hoc test was performed to locate the differences. If a significant group * condition interaction was found a repeated measures anova was performed for each age group to assess differences in condition scores within an age group, and an anova for each condition was performed to assess whether the score of a condition differed between age groups. If data were not normally distributed, the Greenhouse Geiser result was taken. Three-way interactions were ignored. Where a significant difference was identified, a Tukey Post hoc test was performed to determine which groups differed significantly. A univariate analysis of data was used to show the difference between ages. $P<0.05$ was accepted as a significant difference between groups.

3. Results

Sixty-Two participants were recruited and allocated to the following age groups: 19-34 years (Young; Y); 35-59 years (Middle aged; M) and 60-76 years (Older; O). Participant characteristics are shown in Table 1. The first trial for each condition was used for statistical analysis. There were no main effects of sex and no sex * group interactions for any of the measured variables.

Group	Age (years)	Height (cm)	Weight (Kg)	BMI (Kg/m^2)
Young adult (n=27, 18-male)	25.0 (3.7)	174 (9)	75.3 (8.4)	24.9 (1.7)
Middle aged (n=23, 18-male)	44.7 (6.12)	173 (7)	71.2 (4.5)	23.7 (0.9)
Older adult (n=12, 5-male)	67.4 (6.3)	168 (12)	69.4 (11.1)	24.2 (1.2)

Table 4. *Participant characteristics*

Data presented as mean (SD)

3.1 Sensory Organisation Test (SOT)

3.1.1 SOT Equilibrium

For the SOT Equilibrium results, there was a significant condition * group interaction (P=0.013) indicating that the different groups responded differently to the increasing difficulty of the postural challenges working through the SOT tests. This was seen as a lower performance of O than Y and M. Repeated-measures anova showed that each age group (Y, M and O) had significant differences (within age group) across the 6 SOT trials (all P<0.0005) with the tendency for all to decrease performance with increasing difficulty. For Young, using a pairwise comparison, there was a significant difference in scores between conditions 1 and 3 (P=0.033), 1 and 4 (P=0.002), 1 and 5 (P=0.000), 1 and 6 (P=0.000), 2 and 4 (P=0.020), 2 and
5 (P=0.000), 2 and 6 (P=0.000), 3 and 5 (P=0.000), 3 and 6 (P=0.001), 4 and 5 (P=0.000) and 4

and 6 (P=0.005). For Middle Aged, using a pairwise comparison, there was a significant difference in scores between conditions 1 and 2 (P=0.010), 1 and 3 (P=0.010), 1 and 4 (P=0.000), 1 and 5 (P=0.000), 1 and 6 (P=0.000), 2 and 5 (P=0.000), 2 and 6 (P=0.000), 3 and 5 (P=0.000), 3 and 6 (P=0.000), 4 and 5 (P=0.000) and 4 and 6 (P=0.000). For Old, using a pairwise comparison, there was a significant difference in scores between conditions 1 and 2 (P=0.036), 1 and 4 (P=0.008), 1 and 5 (P=0.001), 1 and 6 (P=0.001), 2 and 5 (P=0.001), 2 and 6 (P=0.003),3 and 4 (P=0.037), 3 and 5 (P=0.001), 3 and 6 (P=0.003), 4 and 5 (P=0.002) and 4 and 6 (P=0.008), all shown in figure 1A. Differences in performance between the age groups were assessed by Univariate Anova. This revealed a significant difference for condition 3 between Y and O (P=0.027), and for Condition 5 between Y and O (P=0.028) and MA and O (P=0.021), shown in figure 3A.

3.1.2. SOT Strategy

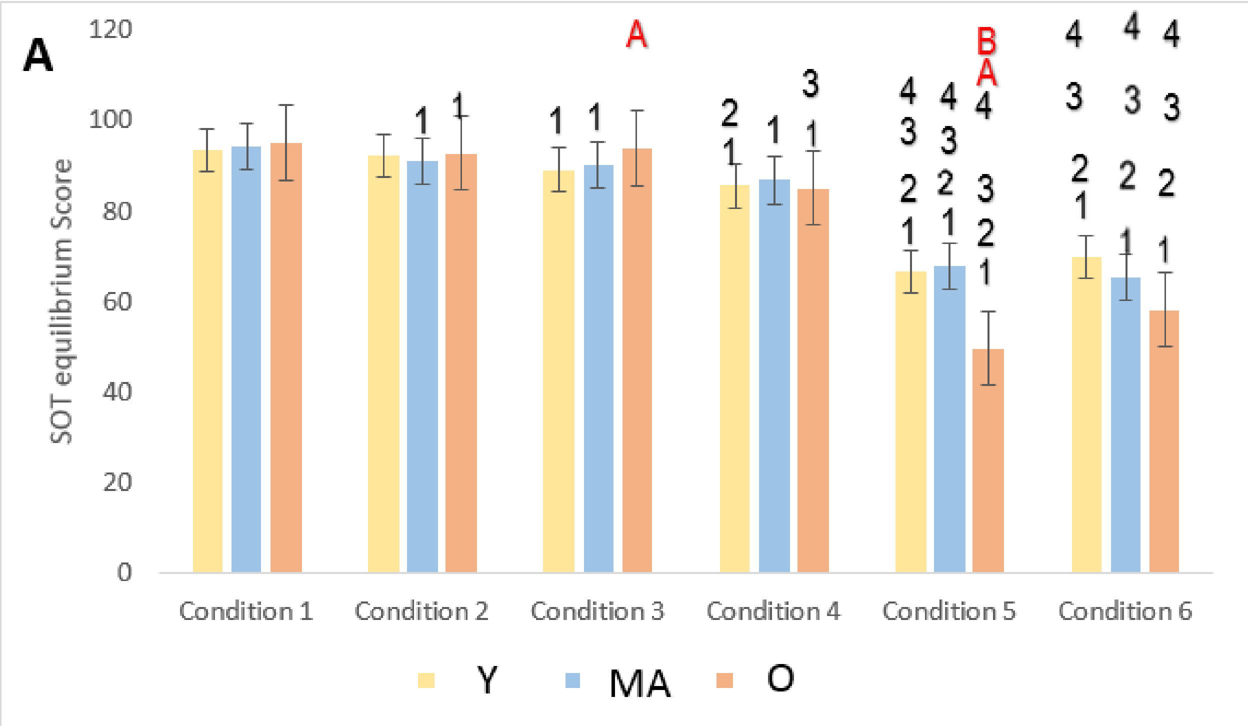
All results for SOT strategy are shown in Figure 1b. There was no significant condition*group effect (P=0.132). Repeated measures ANOVA was performed to assess differences in condition scores within an age group and was significant for Y, M and O (P=0.000), showing that strategy changed with increasing difficulty of the SOT level. For Young, using a pairwise comparison, there was a significant difference in scores between conditions 1 and 3 (P=0.028), 1 and 4 (P=0.000), 1 and 5 (P=0.000), 1 and 6 (P=0.000),2 and 3 (P=0.032), 2 and 4

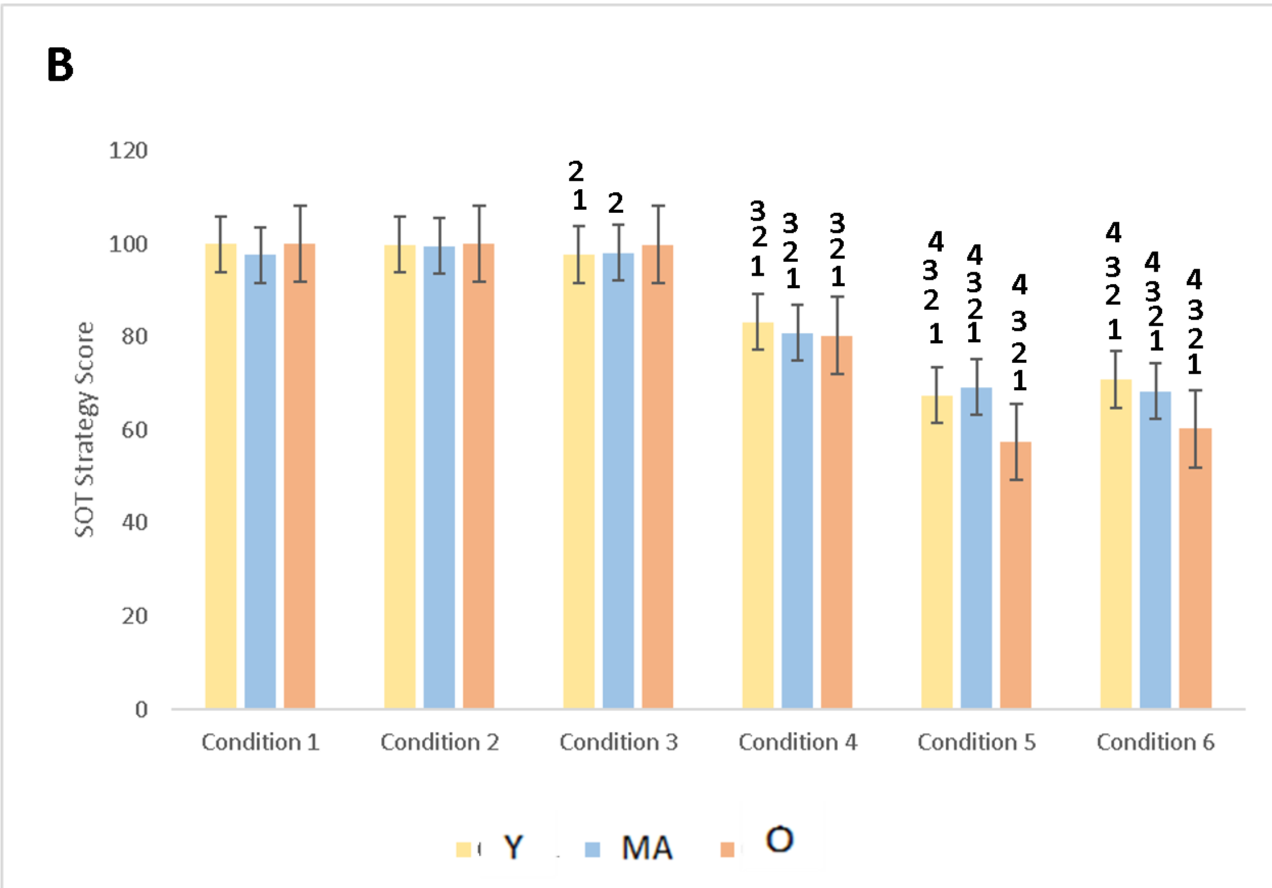
(P=0.000), 2 and 5 (P=0.000), 2 and 6 (P=0.000),3 and 4 (P=0.000), 3 and 5 (P=0.000), 3 and 6 (P=0.000), 4 and 5 (P=0.000) and 4 and 6 (P=0.001). For Middle Aged, using a pairwise comparison, there was a significant difference in scores between conditions 1 and 4 (P=0.000), 1 and 5 (P=0.000), 1 and 6 (P=0.000), 2 and 3 (P=0.043), 2 and 4 (P=0.000), 2 and 5 (P=0.000), 2 and 6 (P=0.000), 3 and 4 (P=0.000), 3 and 5 (P=0.000), 3 and 6 (P=0.000), 4 and 5 (P=0.000) and 4 and 6 (P=0.000). For Old, using a pairwise comparison, there was a significant difference in scores between conditions 1 and 4 (P=0.000), 1 and 5 (P=0.000), 1 and 6 (P=0.000), 2 and 4 (P=0.000), 2 and 5 (P=0.000), 2 and 6 (P=0.000),3 and 4 (P=0.000), 3 and 5 (P=0.000), 3 and 6 (P=0.000), 4 and 5 (P=0.001) and 4 and 6 (P=0.005), all shown in figure 1B.

Using a Univariate Anova to determine differences between ages showed no significant difference for any conditions, shown in figure 3B.

3.1.3 SOT Sensory Analysis

Using a Univariate Anova showed a significant difference for Vestibular Function between MA and O (P=0.026), shown in figure 3C. Scores for somatosensory, visual and the preference of sensory input did not differ significantly between groups.


A
SOT equilibrium Score
0
20
40
60
80
100
120
Condition 1
Condition 2
Condition 3
Condition 4
Condition 5
Condition 6
Y
MA
O


B
SOT Strategy Score
0
20
40
60
80
100
120
Condition 1
Condition 2
Condition 3
Condition 4
Condition 5
Condition 6
Y
MA
O

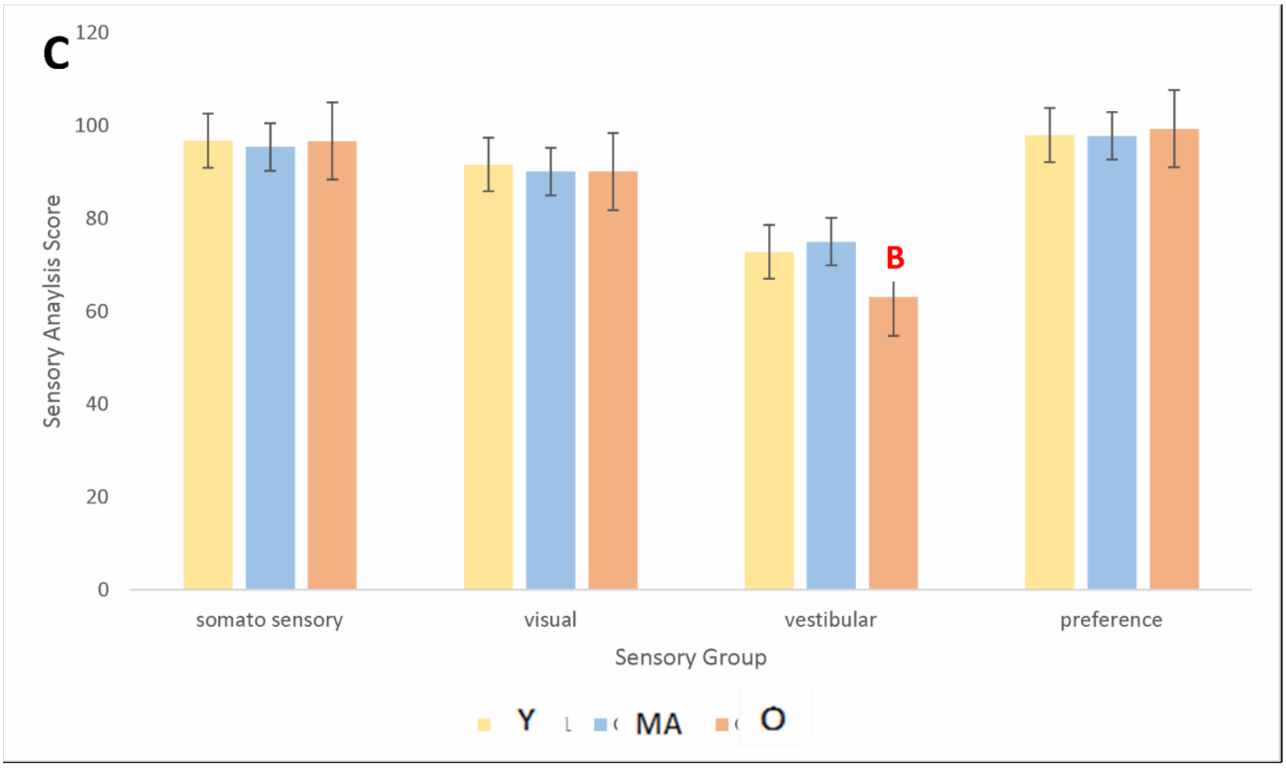


Figure 3 A) Equilibrium, B) Strategy, C) Sensory Analysis Score from the Sensory Organisation Test (SOT). Young (Y): 19-34 years; Middle Aged (MA): 35-59 years; Old (O): 60-75 years. Data shown as Mean ± SEM . 1- differed from condition 1. 2- differed from condition 2. 3-differed from condition 3. 4- differed from condition 4. 5- differed from condition 5. 6- differed from condition 6. A- different to young. B- Different to middle aged.

B

3.2 Motor Control Test (MCT)

3.2.1 MCT Weight Symmetry Results

For the Motor Control test Weight Symmetry there was no significant condition*group interaction (P=0.575). Using a Univariate Anova, to assess differences between ages, there was a significant difference for each Condition. For 'Small Backwards' there was a significant difference between Y and MA (P = 0.034) and MA and O (P = 0.002). For 'Medium Backwards' there was a significant difference between MA and O (P=0.003). For 'Large Backwards' there was a significant difference between MA and O (P=0.012). For 'Small Forwards', 'Medium Forwards' and 'Large Forwards' there was a significant difference between MA and O (P=0.000, P=0.006 and P=0.013 respectively).

3.2.2 MCT Latency (ms)

For the Motor Control test Latency there was a significant condition*group interaction (P<0.0005). Using repeated-measures Analysis of Variance (ANOVA) for each age group showed significant differences in condition score within their age group (P=0.006, P=0.000 and P=0.018 for Y, Ma and O). For Young, using a pairwise comparison, there was a significant difference in scores between conditions 1 (SB) and 3 (LB) (P=0.007), 1 (SB) and 5 (MF) (P=0.001), 1 (SB) and 6 (LF) (P=0.001), 3 (LB) and 5 (MF) (P=0.004), 4 (SF) and 5 (MF) (P=0.016)
and 4 (SF) and 6 (LF) (P=0.021). For Middle Aged, using a pairwise comparison, there was a significant difference in scores between conditions 1 (SB) and 2 (MB) (P=0.001), 1 (SB) and 3 (LB) (P=0.001), 1 (SB) and 4 (SF) (P=0.005), 1 (SB) and 5 (MF) (P=0.001), and 1 (SB) and 6 (LF)
(P=0.001). For Old, using a pairwise comparison, there was a significant difference in scores between conditions 1 (SB) and 3 (LB) (P=0.023), 1 (SB) and 5 (MF) (P=0.021), 1 (SB) and 6 (LF) (P=0.018) and 4 (SF) and 6 (LF) (P=0.042).

Using a Univariate Anova, to assess differences between ages, there was only a significant difference for Large Translations. For 'Large Backwards' there was a significant difference between Y and O (P=0.009) and for 'Large Forwards' there was a significant difference between Y and O (P = 0.042) and MA and O (P = 0.045).

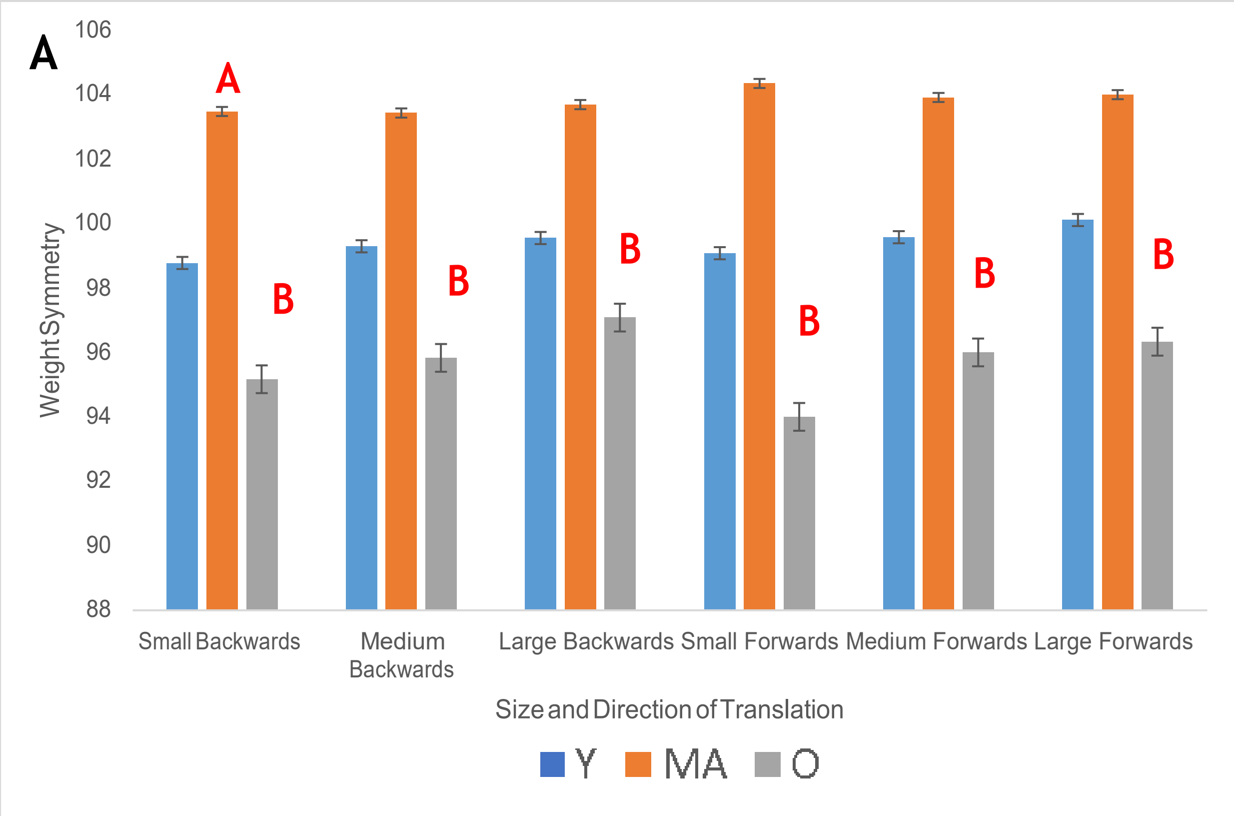
3.2.3 MCT Amplitude Scaling

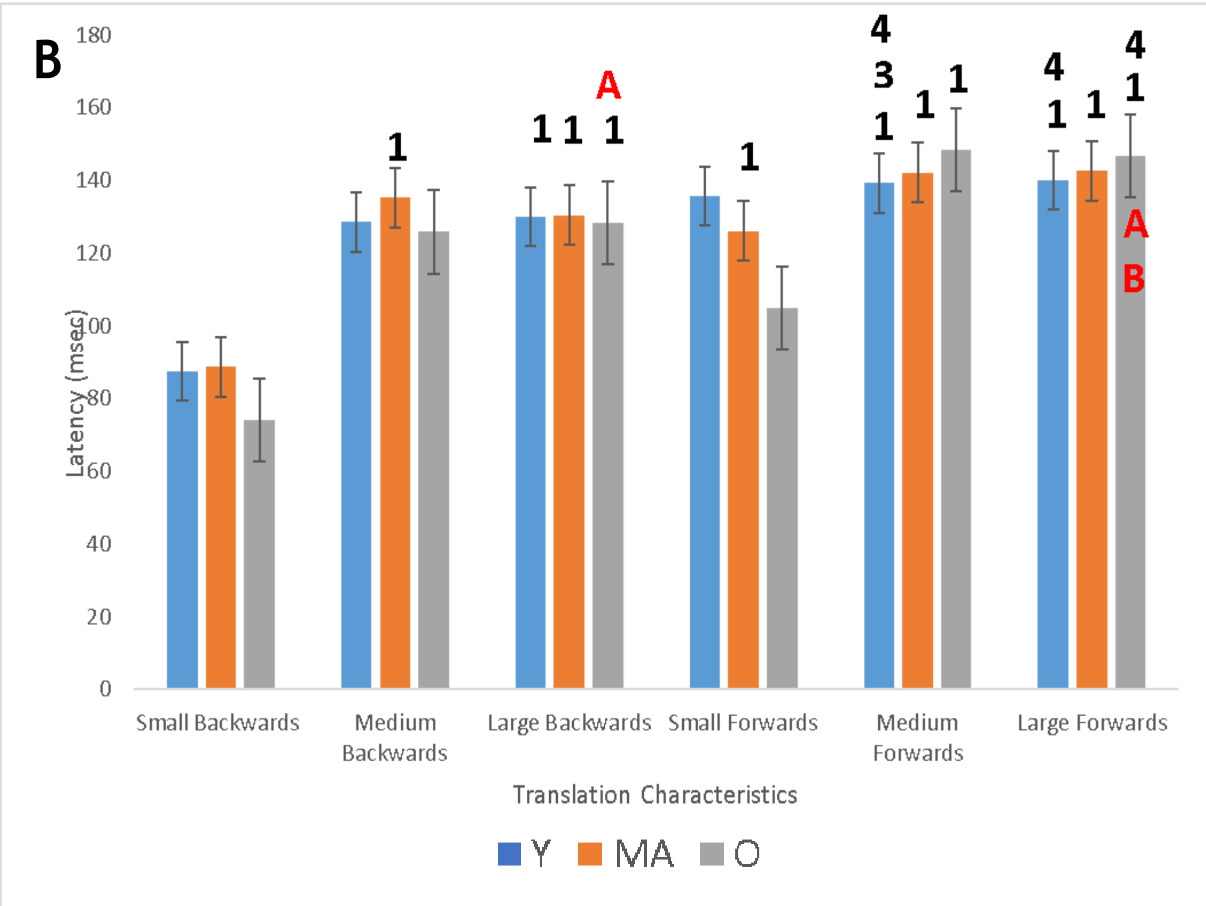
For the Motor Control test amplitude scaling there was a significant condition*group interaction (P=0.000). Using repeated-measures ANOVA for each age group showed significant differences in condition score within their age group (P=0.000, P=0.000 and P=0.000 for Y, Ma and O). For Young, using a pairwise comparison, there was a significant difference in scores between conditions 1 (SB) and 2 (MB) (P=0.000), 1 (SB) and 3 (LB) (P=0.000), 1 (SB) and 5 (MF) (P=0.000), 1 (SB) and 6 (LF) (P=0.000) 2 (MB) and 3 (LB) (P=0.000),
2 (MB) and 4 (SF) (P=0.000), 2 (MB) and 6 (LF) (P=0.000), 3(LB) and 4(SF) (P=0.000), 3 (LB) and 5 (MF) (P=0.000), 4 (SF) and 5 (MF) (P=0.000) , 4 (SF) and 6 (LF) (P=0.000) and 5(MF) and 6(L) (P=0.000). For Middle Aged, using a pairwise comparison, there was a significant difference in scores between conditions 1 (SB) and 2 (MB) (P=0.000), 1 (SB) and 3 (LB) (P=0.000), 1 (SB) and 5 (MF) (P=0.000), 1 (SB) and 6 (LF) (P=0.000), 2 (MB) and 4 (SF) (P=0.000), 2 (MB) and 6
(LF) (P=0.003), 3(LB) and 4(SF) (P=0.000), 4 (SF) and 5 (MF) (P=0.000), 4 (SF) and 6 (LF) (P=0.000) and 5(MF) and 6(L) (P=0.029). For Old, using a pairwise comparison, there was a significant difference in scores between conditions 1 (SB) and 2 (MB) (P=0.000), 1 (SB) and 3 (LB) (P=0.000), 1 (SB) and 4(SF) (P=0.003), 1 (SB) and 5 (MF) (P=0.000), 1 (SB) and 6 (LF)
(P=0.000) 2 (MB) and 3 (LB) (P=0.043), 2 (MB) and 4 (SF) (P=0.004), 2 (MB) and 5(MF) (P=0.039), 2 (MB) and 6 (LF) (P=0.000), 3(LB) and 4(SF) (P=0.000), 3 (LB) and 6 (LF) (P=0.008), 4 (SF) and 5 (MF) (P=0.000), 4 (SF) and 6 (LF) (P=0.000) and 5(MF) and 6 (L) (P=0.002).

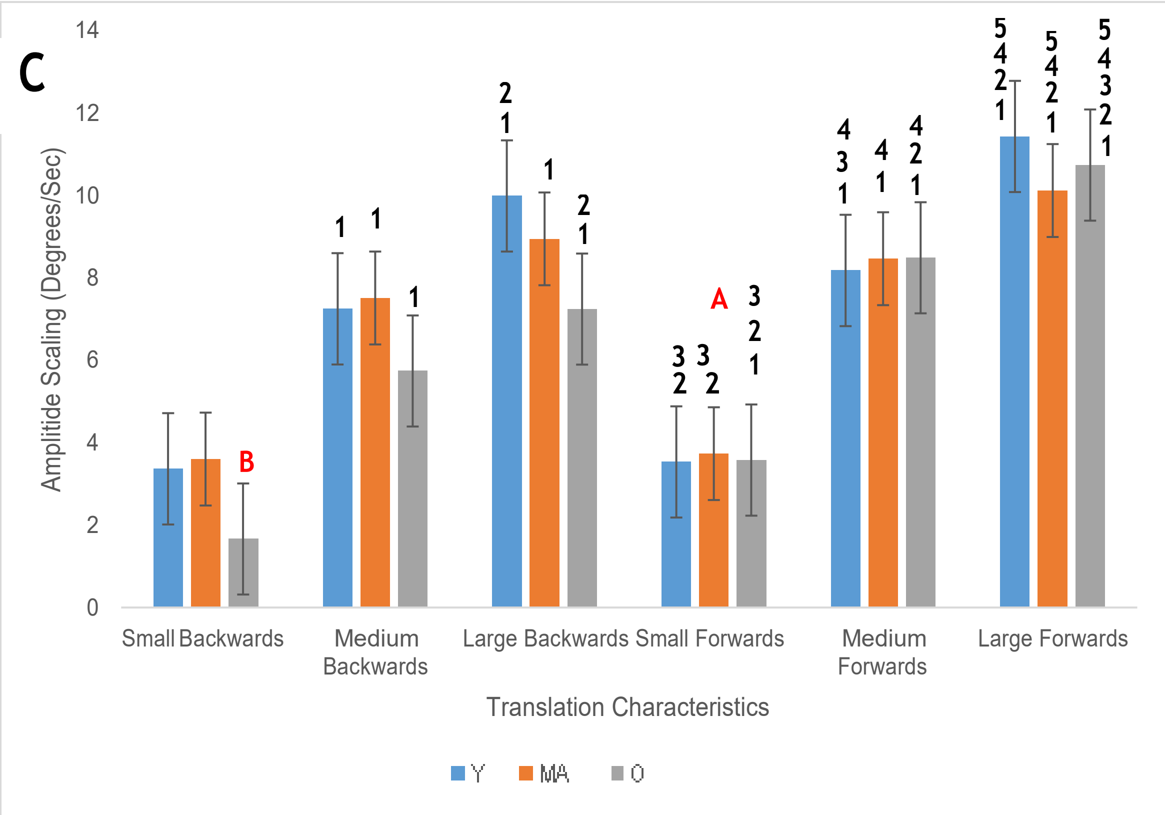
Using a Univariate Anova, to assess differences between ages, there was only a significant difference for Small Translations. For 'Small Backwards' there was a significant difference between MA and O (P=0.036) and for 'Small Forwards' there was a significant difference between Y and MA (P = 0.033).

3.2.4 MCT Strength Symmetry

For the MCT Strength Symmetry there was no significant condition*group effect (P=0.254). Using a Univariate ANOVA, to assess differences between ages, there was significant difference for 'Large Forward' between Y and MA (P=0.016).


A
Weight Symmetry
106
104
102
100
98
96
94
92
90
88
A
B
B
B
B
B
B
Small Backwards
Medium Backwards
Large Backwards
Small Forwards
Medium Forwards
Large Forwards
Size and Direction of Translation
Y
MA
O


B
Latency (msec)
180
160
140
120
100
80
60
40
20
0
1
1 1 1
A
1
4
3
1
1
1
4
1
1
4
1
A
B
Small Backwards
Medium Backwards
Large Backwards
Small Forwards
Medium Forwards
Large Forwards
Translation Characteristics
Y
MA
O



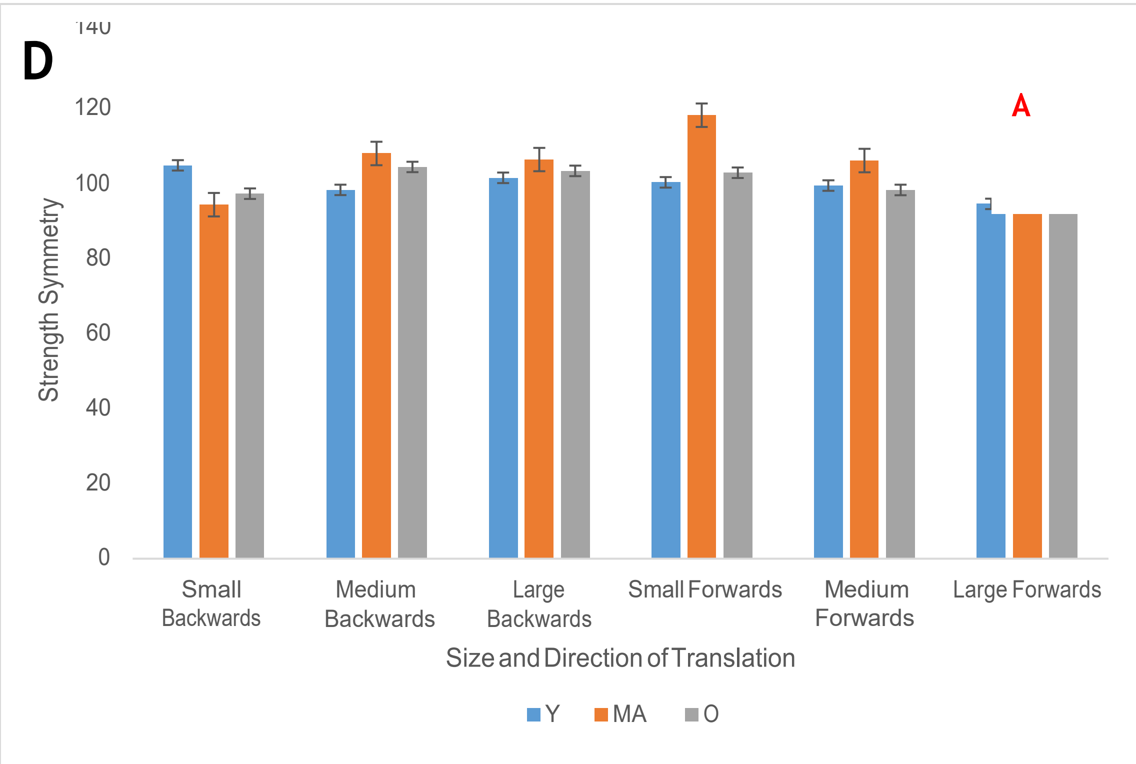


Figure 4. A) Weight Symmetry, B) Latency (msec), C) Amplitude Scaling, D) Strength Symmetry from the Motor Control Test (MCT). Young (Y) :19-34 years; Middle Aged (MA): 35-59 years; Old (O) : 60-75 years. Data shown as Mean ± SEM. 1- differed from condition 1. 2- differed from condition 2. 3-differed from condition 3. 4- differed from condition 4. 5- differed from condition 5. 6- differed from condition 6. A- different to young. B- Different to middle aged.

3.3 Unilateral Stance (US) Test

For the unilateral stance test condition 1 was ‘Eyes Open on the Left Leg’, condition 2 was ‘Eyes Open on the right leg’, condition 3 was ‘Eyes Closed on the left leg’ and condition 4 was ‘Eyes Closed on the right leg’.

For the Unilateral Stance test there was a significant condition*group effect (P=0.003). Using a repeated measures ANOVA for each age group showed significant differences in condition score within their age group (P=0.000. P=0.000 and P=0.000 for Y, Ma and O, respectively). For Young, using a pairwise comparison, there was a significant difference between 1 and 3 (P=0.000), 1 and 4 (P=0.000), 2 and 3 (P=0.001) and 2 and 4 (P=0.001). For Middle Aged using a pairwise comparison there was significant difference between 1 and 3 (P=0.001), 1 and 4 (P=0.000), 2 and 3 (P=0.000) and 2 and 4 (P=0.000). For Old using a pairwise comparison, there was significant difference between 1 and 3 (P=0.001), 1 and 4 (P=0.000), 2 and 3
(P=0.009) and 2 and 4 (P=0.002).

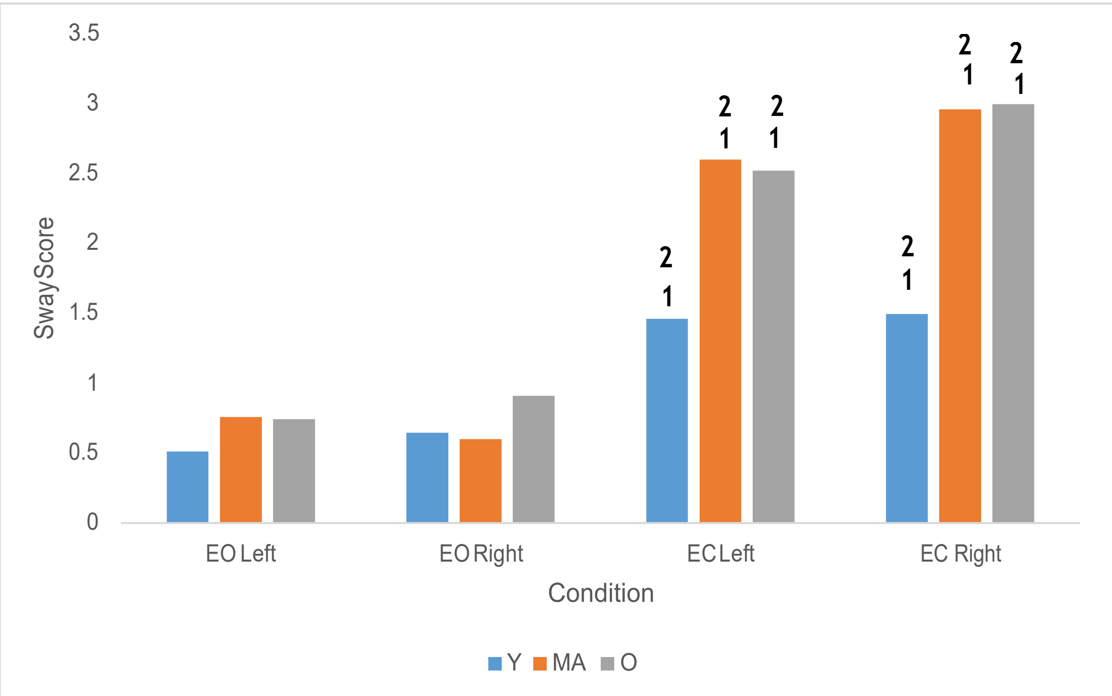


Figure 5 Bar Chart showing mean, standard error, and significant P values for Unilateral Stance Test Sway results for the right leg.

4. Discussion

The purpose of this study was to investigate the Postural Responses to Balance Perturbation in Young, Middle Aged and Older Adults, specifically somatosensory, visual, vestibular and motor system involvement. The main findings of the study indicated that young adults do not need visual input to maintain balance when the visual input is accurate, however when the visual input is disturbed, 'young', 'middle aged' and 'old adults' experience reduced balance stability.

As deficits in balance control have been speculated to come from impaired sensory feedback and integration (Dietz 1992; Horak et al. 1997) or motor impairments (Rougier 2007), the 'Sensory Organisation Test' and the 'Motor Control Test' were used with all participants.

4.1 Sensory Organisation Test

The sensory organisation test (SOT) of Computerized Dynamic Posturography can objectively identify any abnormalities in the visual, vestibular and somatosensory systems by isolating various sensory contributions, by either removing or distorting the visual and/or somatosensory inputs to the postural control (Wrisley et al, 2007).

4.2 Visual System

Although balance is maintained through a combination of the visual, vestibular and somatosensory system inputs, it is widely accepted that vision is the primary sensory system used in balance (Poole, 1991, Merla and Spaulding 1997, Uchiyama and Demura, 2009). For example, human balancing during upright stance is more stable with eyes open than with eyes closed (Horak & Macpherson, 1996).

In relation to the visual strategy, we hypothesised that 'Old' would have a reduced visual strategy compared to 'Young' and 'Middle Aged'' and that 'Confused visual input will disturb balance at all ages'.

The SOT equilibrium score is an overall indicator of balance scaled from 0 to 100 where 100 indicated perfect balance. Effective spatial orientation, postural control and balance requires the integration of proprioceptive, vestibular and visual inputs, and a low equilibrium score indicates a balance impairment caused by an inability to effectively use one or a combination of these senses.

The results from the SOT equilibrium test suggest that the 'Young' do not rely on having a visual input to maintain balance, however when the visual input they receive is inaccurate, they struggle to maintain postural balance. This suggests that receiving inaccurate visual information is more detrimental on balance than not receiving any visual information in the 'Young'. For Young, where there are inaccurate visual cues in addition to support surface disturbance, balance does reduce significantly, as suggested by the significant difference between condition 4 and condition 6. However, when either the young receive on balance conflict, visual or support, the balance deteriotion is similar suggesting that in young it does not matter what effects the balance.

Results for 'young', 'middle aged' and 'old' show a significance difference between condition 1 and condition 4, suggesting that when visual input is confused there is a significant reduction in balance ability. From this, we can accept our hypothesis that 'Confused visual input will disturb balance at all ages'.

For 'Old' there was no difference between conditions 1 and 3 suggesting that inaccurate visual cues had less of an effect on old compared to middle aged and young, leading us to accept our hypothesis that 'Old have a reduced visual strategy'.

The equilibrium scores show a significant difference between 'Young' and 'Old' for 'Condition 3'. This implies, that when visual cues are inaccurate, there is a greater effect on the balance of 'old;' compared to 'young'. The significant difference between young and old and middle aged and old for condition 5 suggests that when there is no visual input and the support surface is unstable the balance for 'old' is much worse than for young and middle aged, contradicting our hypothesis that 'old have a reduced visual strategy'.

These results are contradictory as although there was no significant difference in balance when there was a disturbed visual surround for old compared to standing still, there was a significant difference between old and young when there was a disturbed visual surround. This could be explained as young have a better visual strategy than old, so the disturbed visual surround did not negatively effect their balance, compared to the old. However, as the older adult already had a reduced balance when standing still, there was not a significant difference shown.

4.3 Somatosensory System

Balance in the elderly population is a major concern due to the often catastrophic and disabling consequences of fall-related injuries. Structural and functional declines of the somatosensory system occur with ageing and potentially contribute to postural instability in older adults. The somatosensory system processes information including pain, temperature, touch and proprioception. It is a complex system of sensory neurons and pathways that respond to changes at the surface or inside the body. The somatosensory system was tested when reliable proprioceptive information from the feet and ankles was altered by creating an unstable support surface. As there was no significant difference between results for the SOT equilibrium test between condition 1 and condition 2 for 'young' it is assumed that the 'young' are able to use the somatosensory system to maintain balance, which may be why balance is maintained when there is not visual input. However other studies have suggested that the visual system is the predominant sensory system used by young adults to maintain optimal postural balance (Gaerlan et al, 2012), suggesting that the somatosensory system will only be relied on when there is no visual input.

Several studies have looked at age-related changes effecting touch sensation and its impact on postural stability in the elderly. Peripheral sensation seems to be an important factor in maintenance of postural stability whilst standing still (Wickremaratchi et al, 2006). Others have highlighted the importance of somatosensory input and muscle strength in the maintenance of postural stability in the elderly (Corriveau et al, 2004). As the SOT equilibrium results suggest 'Middle Aged' and 'Old' are unable to rely on the somatosensory system to maintain balance, it implies that there is a deterioration of the somatosensory system between young and middle aged. Although there is thought to be a continued decline in the somatosensory system with ageing, the effect in balance does not significantly further decline from 'Middle Aged' to 'Old in our study.

As it is suggested that middle aged and older adults are unable to rely on the somatosensory system to maintain balance, it could explain why there is an increased incidence of falls with ageing. Multiple studies have indicated sensory receptors that monitor body orientation become less sensitive with ageing (Goble et al, 2009) resulting in an increased incidence of falls (Horak, 2006) and an overreliance on visual feedback (Simoneau et al 1999) which can disrupt postural control when visual inputs are altered or unreliable (Jeka et al, 2010).

4.4 Vestibular System

The vestibular system, which provides a leading contribution to the sense of balance and spatial orientation for the purpose of coordinating movement with balance, is thought to be effected by ageing alongside the visual and the somatosensory systems. It is comprised of peripheral sensory end organs and a complex network of central neurons. The peripheral anatomy and physiology are responsible for sensing the degree and direction of acceleration, as well as providing a sense of orientation of the head with respect to gravity. The central connections, including the vestibular nuclei, are responsible for processing the numerous sensory inputs. Although the impact of the vestibular system on balance is difficult to quantify, the damaging impact of ageing on the vestibular system is serious both medically and economically however the measurable impact from these anatomical changes remains indefinable. Tests of vestibular function are often unable quantify such anatomical deterioration, or they are insensitive to the associated physiologic decline and/or central compensatory mechanisms that accompany the vestibular age
ing process (Zalewki, 2015).

The equilibrium results imply that the young, middle aged and old cannot rely on the vestibular system to maintain balance, as there is a significant difference between condition 1 and condition 5, suggesting that this sensory system needs to be used in combination with the other sensory systems, but the contributions of the vestibular system are undoubtedly critical. This is particularly evident when functioning in vestibular-dependent environments where visual and somatosensory cues are compromised (Peterka, 2002).

The significant difference between young and old and middle aged and old for condition 5 suggests that when there is no visual input and the support surface is unstable the balance for ‘old’ is much worse than for young and middle aged.

The results from the sensory analysis, which reflect the sensory ratios computed from the average equilibrium, showed a significant difference in vestibular function between middle aged and old. This implies a significant reduction in ability to use the vestibular system to maintain balance in once in the 'Old' group.

4.5 Ankle Strategy vs Hip Strategy

The relative amount of movement about the ankles, known as 'ankle strategy' and about the hips, known as 'hip strategy', used by the participants to maintain balance during each trial was quantified using the strategy analysis from the 'Sensory Organisation Test'.

Normally, individuals would rely on ankle strategy when on a stable surface and transition to hip strategy as the surface became unstable. A score near 100 indicates a full ankle strategy, whereas a score near 0 indicates a full hip strategy. These strategies can be used separately or together in varying degrees to produce optimal and adaptable balance control, depending on the difficulty of the balance task (Hwang et al. 2009).

The ankle strategy, which is designed to use its surrounding musculature to maintain an upright position, involves delayed activation of the ankle, thigh and trunk muscles radiating distally to proximally on the same dorsal or ventral aspect of the body. When the perturbation is larger than that the ankles can correct, the ankle strategy is no longer sufficient to prevent a fall, which often leads to a hip strategy being used. The hip strategy involves the delayed activation of the trunk and thigh muscles, radiating in a proximal-to- distal fashion. For example, in response to a posterior movement of the support surface the ankle strategy would result in activation of the ankle plantar-flexors, knee flexors and hip extensors, while the hip strategy would result in activation of the knee extensors and hip flexors. The hip joint can also move in all directions; therefore the hip is also a great joint to defend against falling because it can correct any medium to large perturbation in any direction. The last defence against a fall is the step strategy, which was marked as a fall on the balance master, and this occurs when the perturbation is so large that the hip strategy is not sufficient.

The strategy analysis suggested that there was not a significant difference between age groups with which strategy was used. This suggests ageing is not a factor effecting strategy. Therefore, we rejected the hypothesis that ‘Old would use a hip dominant strategy’ and accept the null hypothesis.

Although this finding is contradictory to other findings that suggest that the elderly tend to use more of a hip strategy (Kanekar and Aruin, 2014), an ankle joint strategy is ordinarily used when there is a small amount of body sway on a solid base of support. It is the first postural adjustment strategy to be used and refers to primarily recovering upright standing balance through muscular contraction of the ankle joint (Choi and Kim, 2015). This suggests that although hip strategy can become dominant with age, the ankle strategy is the normal preferred strategy to prevent falls.

For conditions 1, 2, and 3, nearly a complete ankle strategy was used whereas for 4, 5, and 6, a combination strategy was used. Although this was primarily ankle strategy, the involvement of hip strategy when the support surface was unstable suggests that when the body is moved outside of its normal parameters the body relies on a hip strategy to maintain an upright position.

4.6 ‘MCT’ Latency (ms)

Response latency is defined as the time in milliseconds between the onset of force plate translation and initiation of the active force response in a leg, to prevent a fall. There was a significant difference between condition scores, independent of age. Therefore, we assumed that the size and direction of force plate translation is directly linked to response time, and this reaction is not effected by age.

However, the results showed a significant difference in response latency between ‘Young’ and ‘Old’ for all large translations. This implies that once the translations reach a specific size, the elderly have a significantly slower reaction time than the young, which suggests that with ageing response speed is slower. This can lead to falls, due to taking too long to correct balance. The significant difference between Young and Middle aged for large forwards translations, suggests that for forwards translations, the effect of ageing begins younger than for backwards, as it also effects the middle aged compared to young. A study carried out by Youn et el, divided a group of fallers by fall direction, with 45 out of 62 being forwards fallers (Youn et al, 2017). This suggests that falling forwards is more common and may explain why there is a significant difference for forwards translations between young and middle aged.

4.7 MCT Amplitude Scaling

The amplitude scaling represents the strength of each leg following the translations. The significant difference between condition score for Y, MA and O suggests that the size and direction of translation effects the efficacy of response for all ages.

For Old, there is a significant difference between forwards translations and backwards translations for small, medium and large translations, implying that the direction of the translation only effects the amplitude for a set size once participants are 'Old'. As scores are higher, reflecting more movement per second for forwards translations, it suggests that the elderly struggle to correct balance more when the translations are forwards.
However, there was only a significant difference in amplitude scaling between age groups for small translations. This suggests that when translations are larger than small, age is not a contributing factor to how the participants react to it.

4.8 MCT Strength Symmetry

MCT strength symmetry represents the symmetry of balance response between each leg. For example, if one leg had a significantly larger response than the other did, this could decrease balance. In a study by Hamada et al, normal subjects demonstrated a high degree of symmetry of response strengths for both legs and both directions of translation. Because the neural pathways innervating each leg and mediating backward and forward movements

were relatively independent, asymmetries of strength could occur in many combinations (Hamada et al, 2014).

The lack of significant difference between conditions for all age groups suggested that the size and direction of translation does not effect strength symmetry. This could suggest that strength symmetry is not heavily involved in balance. However, a significant difference was identified for 'Large Forwards' translation between 'Young' and 'Middle Aged' suggesting that middle age have significantly less strength symmetry than Young.

The conservation of muscle strength during ageing is vital. However, in healthy elderly people a reduction in muscle mass and muscle strength is usually observed (Lexell, 1995). Lower extremity muscle weakness and power and balance impairment are major independent intrinsic contributors to falls and susceptibility to intervention. The association between postural stability and muscular strength of the lower limbs received little attention in the literature although the gradual loss of muscle strength results in functional impairment and in an increased risk of falling (Wolfson et al, 1995). A consequence of reduced muscle strength would be a reduction in strength symmetry.

4.9 MCT Weight Symmetry

During the trial, when the participants' feet are properly placed on the dual force plate, weight symmetry scores near 100 indicate that both legs are carrying equal weight. Values to the right or left of the normal limits indicate that there is a disproportionate amount of body weight being either carried by the right or left leg.

For all conditions (size and direction of translation), there was a significant difference between 'Old' and 'Middle Aged'. This suggests that once participants are 'Old', there is a significant reduction in weight symmetry. Although Gait and balance disorders are common in older adults and are a major cause of falls in this population (Salzman et al 2016), not many studies have looked into weight symmetry as a cause for balance loss in the older population.

4.10 Unilateral Stance Test

The unilateral stance test quantifies the ability to maintain postural stability whilst standing on one leg, with eyes open and eyes closed. Reasons Causes of participants showing signs of being unstable include difficulty using visual or somatosensory information for balance control, and/or musculoskeletal problems that make it difficult to correct lost balance.

There was a significant difference for ‘Young’, ‘Middle Aged’, and ‘Old’ between all conditions, suggesting that having eyes open/closed, and the leg being stood on effects balance. This also implies that balance stronger when stood on the dominant leg, as there is a significant difference between legs.

For both the right and left leg there was significant difference between eyes open and eyes closed, this suggests that when stood on one leg, visual input is vital for maintaining balance, supporting the hypothesis that ‘Visual Input is crucial for maintaining balance at all ages’. As there is no significant difference between ages, it implies that age is not a factor effecting unilateral stance stability.

4.11 Limitations

Although a large sample of data was collected from 62 participants, there were only 12 participants in the ‘Old’ group. A larger sample size for this age group, with a more equal gender split would have been more representative of the general population.

Participants with visual impairments were allowed to be included in the study, if they wore their normal corrective glasses. However, no further assessment was taken. This could have effected the results of the study. If a repeat of the study was conducted, it would be better to not allow participants with visual impairments in case this effected the results.

4.12 Conclusion

With increasing age, the balance function of older people will decline (Schmitz et al, 2007), such as decreased nerve conduction velocity (Valerio et al, 2004e), increased central processing time (Finkel et al, 2007), decreased muscle strength (Perry et al, 2007) and increased passive tissue stiffness (Devita et al, 2000). The deteriorated balance function may increase the risk of falls in older adults (Melzer et al, 2004). Alongside ageing, there are other factors, which can effect the rate of balance decline including gender and education level (Fang et al 2015). Exercise, such as long term physical exercise (Seco et al 2013), can also effect the rate of balance decline, with older people who practised tai chi being more likely to maintain a stable posture while doing challenging balance tasks (Wong et al, 2001).

Sleep deprivation can also effect balance performance, with subject who experienced one night of sleep deprivation demonstrating postural instability (Ma et al, 2009).

The Hypothesis that 'Visual input is crucial for maintaining balance for all ages' was accepted, which suggests that the visual system is one of the most important for maintaining balance. We also discovered that 'Young' adults are the only age group in the study, which were able to rely on the somatosensory system to maintain balance, whereas none of the age groups could use to vestibular system alone to maintain balance.

4.13 Implications for future research

This research would be a good foundation to a training study, to investigate the effects of exercise on improving postural balance, with the aim to reduce the incidence of falls, particularly amongst the elderly.

Loss of muscle mass and slowing of movements seem to be inevitable changes in old age. They are associated with poor balance and high falls risk. The most effective way to reduce falls risk is exercise which should provide a moderate or high challenge to balance and be undertaken for at least 2 hours per week on an ongoing basis. (Sherrington et al., 2011).

This could include standardised assessments of leg strength and power, as well as more detailed measurements of postural control under steady conditions and responses to perturbation (using the Balance Master). Participants could then complete exercise training to improve physical function and balance amongst the elderly. Assessments could include detailed neuromuscular imaging (MRI and DXA) and motor unit recordings (surface and intramuscular EMG) during isometric contractions. They could also include a sensory organisation test using the Equitest

Balance Master to identify deficits to vestibular, visual and proprioceptive inputs (Palumbo et al., 2001).

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APPENDICES

7.1 Participant Consent Form

Date
Name
Course
Department
Building
Manchester Metropolitan University
Tel:

Manchester Metropolitan University

Consent Form

Title of Project: POSTURAL RESPONSES TO BALANCE PERTURBATION IN YOUNG AND OLDER ADULTS

Name of Researcher: Supervised by Prof J McPhee and Prof H Degens

Participant Identification Code for this project:

Please initial box

1. I confirm that I have read and understood the information sheet dated …. for the above project and have had the opportunity to ask questions about the experimental procedure.
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason to the named researcher.
3. I understand that my results will be recorded and used for analysis for this research project.
4. I give/do not give permission for my results to be archived as part of this research project, making it available to future researchers.
5. I understand that my results will remain anonymous.
6. I agree to take part in the above research project.
7. I understand that at my request my results can be made available to me.

Name of Participant	Date	Signature
Researcher	Date	Signature

To be signed and dated in presence of the participant

Once this has been signed, you will receive a copy of your signed and dated consent form and information sheet by post.